THE PATHWAY FROM VISION TO ACCOMPLISHMENT IN AERONAUTICS

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(The 1950 Martin McCue Lecture at the University of Notre Dame, November 9, 1950)

Have you ever stopped to consider that every accomplishment of the human race must have been preceded by the vision of that accomplishment in the mind of some man or woman? Before the rough lump of marble can be transformed under the tool of the sculptor to reveal the living forms imprisoned within it, the sculptor must see these forms with his mind's eye. Before the brick and mortar and stone and steel can be assembled to rise as the treasured home of a great university or as an inspiring cathedral, some fellow man must have had a vision of what could be and must have followed the pathway from vision to accomplishment.

So, too, in aeronautics. The speedy and comfortable airliner in which the representatives of all the nations of the world may travel to their place of assembly within 50 hours existed first in that invisible world of the mind. The extensive network of airlines to exploit the potentialities of the airplane to serve the needs of men also was first conceived, and only later become a reality. This process continues today. Men are dreaming dreams, stirred by longings for still greater accomplishments. Dreams sharpen to visions which point to the pathway toward realization. This is the fruit of the creative genius of man, that inheritance which sets him apart from other animals, and by which he can completely change his physical and spiritual environment. Let us explore aeronautical development from this point of view.

The First Travellers

Prior to the vision comes the dream. Probably in times so ancient that no written records are left, the freedom of the birds taking off from the ground to ascend into the high atmosphere and the larger birds soaring without apparent effort stimulated the desires of many men and led to dreams of emulating the example of the birds. The first ideas were, however, more direct. In his book on the Civilization of Babylonia and Assyria, Jastrow mentions one of the early heros, Etana by name, of whom the story is told in the ancient records of an attempted flight to heaven on the back of an eagle. Other legends tell of other attempts to use birds as the motive power for human flight. Such employment of the abilities of birds in the service of man seemed as feasible in those days as the domestication of the ox.

Many of the legends were more characteristic of man's primitive concepts of Nature and of his belief in its control through magic. The magic flying carpet of the Arabian Nights is a means of aerial transportation whose motive power appears entirely supernatural to our generation, however it may have appealed to the originator of the tale many centuries ago. The modern teller of tales of space ships equipped with anti-gravity shields is perhaps a descendant of the ancient narrator.

From the harnessing of birds to his aerial chariot man turned to dreams of supplying Nature's lack and equipping his own body with wings. Greek mythology tells the story of Daedalus and Icarus familiar to every school boy. Daedalus, who built the famed labyrinth of Crete for King Minos, fell into disfavor with the King and he, with his son Icarus, was imprisoned. Daedalus constructed artificial wings of feathers and wax for himself and his son to make their escape. Icarus flew so high and so close to the sun that the wax melted and he fell into the sea, but according to the story, Daedalus made a successful flight.

These were some of the early gropings to find the entrance to the path leading to the accomplishment of human flight. Through the centuries of the Christian era some men dreamed while others, the progenitors of the modern aeronautical engineer, sought to apply the limited scientific and engineering knowledge of their day to a most challenging problem. The path was explored step by step. The number of workers who made substantial contributions may never be accurately known; it is certainly very large. Some 59 scenes from the history of aeronautics prior to the Wright Brothers are depicted on the walls of the entrance lobby of the administration building of the NACA Langley Aeronautical Laboratory. The great majority of these are much more than mere dreams. The men responsible for these events had conceived methods of accomplishing human flight which appeared feasible in the light of their past experience and the knowledge of other men's work accessible to them. They had exhibited creative thought and were men of vision. Progress along the path towards accomplishment was possible only to those who went beyond dream to vision, to men who attempted to fashion the materials and methods of their day to new purposes.

The embodiment of the visions of the earliest pioneers into practical devices was handicapped, partly by the absence of suitable materials, but chiefly by the primitive sources of power available. Practically speaking, human power was the only possible source. When the power of steam was harnessed, the boundaries of possible accomplishment were widely extended. In the nineteenth century, Henson, the first to propose a monoplane, Marriott, Aders, Cayley, Langley, Phillips, who developed the curved lifting surface or airfoil, Moy, and Maxim are among those who experimented with steam engines. Maxim's airplane model, built in 1893, was 110 feet long, weighed 3 - 1/2 tons, and was powered by a 350-horsepower steam engine driving twin propellers about 17 feet in diameter. It ran on a restraining track and actually lifted itself with Maxim aboard. However, as Maxim himself knew, it was not controllable in the air and to have attempted free flight would have been disastrous.

The first controlled human flight, as all the world knows, was made by Orville Wright on December 17, 1903 at Kitty Hawk, North Carolina. The Wright airplane was powered by an internal combustion engine of about twelve horsepower. This first accomplishment of human flight for a distance of

120 feet in 12 seconds now seems quite unimpressive. But it had been envisioned and seriously sought for several hundred years.

The first travellers to arrive at the first goal, Wilbur and Orville Wright, were soon followed by many others who set themselves successively higher goals. Now, forty-seven years later, we may travel in comfort at a speed of 300 miles per hour over air routes which encircle the globe and experimental flights are in progress on jet-powered airliners of greatly increased speed. In special research airplanes speeds well above the speed of sound have been attained. New power plants of the jet and rocket type and new knowledge of the motion of the air around objects at high speeds have greatly accelerated the rate of increase of aircraft performance. Greater and greater accomplishments are in prospect as men succeed in travelling the pathway from vision to accomplishment.

The Pathway

As has been outlined the pathway was explored by many men over many generations, each new explorer contributing his new concepts and in many cases at least a partial realization. For a number of years following the first successful flight it was possible for any individual to travel the pathway in a few years of his own lifetime. He could learn and know all there was to be known about aeronautics and aircraft design. As recently as 1918 as a young graduate student I was assigned the task of reading up and summarizing the knowledge of the physical principles employed in aeronautics. The situation soon changed. Today it is very difficult to discover the designer of one of our modern airplanes. It is the product of a large organization of many specialists of many types, of a team. No member of the team can comprehend the final product in all its detail. When you examine this modern airliner you do indeed wonder how any one man could have invented or designed it. Of course no one man did or could. Its development rests on the contributions of many men in the past and of many men now living. The pathway has thus become very complex, in fact many pathways have been followed by many men all converging on a common goal just as the network of highways converges on a modern large city.

Yet in spite of the enormous differences I still maintain that the concepts must originate in the minds of men before there can be any physical accomplishment. Even the intensive organization of specialist skills, the layout of the pathways to converge on a common goal, whether we consider a new airplane or a new airline, must itself be envisioned by the mind of some man before the steps toward accomplishment can begin. Vision is still the first step.

Vision is guided nowadays not only by the experience and accomplishments of the past but by a specialized and somewhat artificial type of experience known as scientific research, to which many men devote their lives. Modern science, which seeks to know and understand the laws of Nature--how air flows around bodies; what forces, pressures, and loads are exerted on bodies moving through the air; how materials and structures behave under load--is the secure foundation on which all engineering accomplishment rests. Theoretical and experimental research, a cultivated and controlled type of experience, supplies the proper food for thought to nourish a realizable vision.

The feeding of the results of the experiences of other people into the mind does not, however, make a good engineer or creative designer. The distillation of the discoveries of other men into an engineering handbook may provide sufficient basis for the training of engineers in some fields in which economy of materials and refinement of design are unimportant, but handbook engineers are of no value in aeronautical development today. Likewise mere training in the knowledge and techniques of the aeronautical sciences will not make a good member of an aircraft design team. The art of inventive application must also be mastered, the art of finding new means to old ends, skill in finding new combinations of old elements. Problems must be met not only with correct scientific and technical knowledge but also with ingenuity. Thus before the real journey along the pathway towards accomplishment begins, the concept must grow and develop within the mind and through creative activity of the mind the entrance to the pathway which leads to the desired goal must be found.

The next step is to send out exploring parties, to make forays to verify or modify the intended course. This is the activity of applied research.

The questions are now asked of Nature. You recall Boss Kettering's approach of asking the Diesel engine rather than a consulting engineer whether a given design of piston was good or not. The theoretical and conceptual ideas must be given the acid test of actual trial. If the theory proves wrong, if one approach does not make progress toward the goal, the intelligent engineer will seek a new theory or a new approach. In aeronautical development we find need for a great deal of applied research, some of a very specific nature directed to limited objectives, some of a very general nature directed to broad objectives. The result of all this activity is to establish confidence that the vision is a realizable one, that the foreseen problems can be solved. The unforeseen problems are another and later story.

The scene now reverts to the immaterial sphere of the mind. The problem now is to sharpen the vision to an integrated and coordinated design in which the necessary compromises between conflicting requirements have been made, the solution being consistent with demonstrated possibilities of achievement. The designer is a creative artist like the architect, who with a given site on a rocky hillside, a given family with certain living habits and needs, and a certain supply of available materials plans a structure which most harmoniously meets the given conditions. Or, the designer is like the composer of a great symphony, who knows the characteristics and capabilities of all of the different instruments and must write the score for all. The result is to be a unified and integrated composition. The success or failure is in the composer's hands and is decided before the orchestra plays a single note.

The symphony orchestra conductor now takes over from the composer; the builder from the architect; the production engineers and artisans from the airplane designer. Their job is to make the vision come true, to turn notes into music, plans into houses, acres of blueprints into a structure of aluminum, steel, and plastic--an airplane. At every step the same cycle of mental-physical activity is repeated. Each accomplishment is preconceived in the mind of man and the more creative, the more inventive, the more experienced, and the more intelligent the man who conceives and plans, the more advanced and the more suitable to its purpose is the resulting product.

Now come the unforeseen problems as the user takes over. The new airplane is born not to be set on a pedestal to be admired for its beauty, for the complexity of its construction, or for its cost. It was made to serve a purpose; it is a tool to accomplish the purposes of man, in transporting him and his possessions, or in fighting his enemies. The infant airplane moves from the sheltered walls of the factory to a hard, cruel, and abusive world. It's rained on, hailed on, frozen and scorched, pounded by gusts and hard landings. The process of evaluation and further development to overcome shortcomings begins. Here again the activity of the mind precedes that of the hand and predetermines the effectiveness of the result.

Such is the general character of the pathway from vision to accomplishment. May I illustrate it a little more concretely with the base skeleton of the story of the modern turbojet engine. As you perhaps know, many men dreamed of this general type of engine but it remained for Frank Whittle to traverse successfully the pathway to accomplishment. The vision may perhaps be illustrated by his earliest patent, British Patent No. 347, 206, filed January 16, 1930. This patent contains the necessary elements, compressor, combustion chamber, turbine, and exhaust nozzle. Success was greatly dependent on both basic and applied research, particularly on compressors, combustion, and high temperature materials. When Whittle submitted his engine to the governmental authorities in Great Britain, it was rejected as inoperative. I have heard Whittle state since, that they were probably correct in their judgment at the time, but he himself did not give up. Whittle and his associates conducted applied research on many problems, and designed and constructed the first model to be tested under its own power on April 12, 1937. This was followed within a few years by the W-1, the flight engine of about 850 pounds thrust. An experimental airplane powered with the W-1 engine flew successfully on May 15, 1941. The same airplane equipped with the W-1X had taken off during taxi tests in March 1941. The W-1X engine was presented to the Smithsonian Institution last year. Much development followed and is continuing today at a rapid pace. A typical modern jet engine has a thrust of 7 or 8 times that of Whittle's first engine.

Expanding Vision

There is an interesting group of statements in the last Aeronautical Yearbook of the Aircraft Industries Association under the colorful heading "Quotes That Failed". These are collections of forecasts, some by very famous men, which turned out to be wrong. Looking backward from our time, many of them appear somewhat foolish. It is an interesting exercise to look back on other prophecies which were more nearly correct and to compare the prophecies with the facts.

On the occasion of the 30th anniversary of the first flight of the Wright Brothers, Captain J. Laurence Pritchard, Secretary of the Royal Aeronautical Society of Great Britain wrote an editorial in which he asks, "What of the next thirty years?" Answering his own question he predicts among other things aircraft speeds of 1000 miles per hour. Security considerations do not permit me to state whether this speed has or has not been exceeded today after only 17 of the 30 years have passed. There are, however, research airplanes under construction designed to be flown at speeds well beyond 1000 miles per hour and their prospective flight dates are within the next two or three years. Pritchard's prophecy therefore now looks very conservative.

In Popular Aviation, December 1939, Hall Hibbard, now a vice president of the Lockheed Aircraft Company, predicted that in January 1950 we would have 75-ton airplanes carrying 100 passengers at better than 300 miles per hour. He supplied the detail that the engines would be in-line liquid cooled engines and that 4 to 6 of them would be used to power the airplane. Except for the fact that the engines turned out to be aircooled, this was a remarkably accurate prediction.

Another interesting prophecy is that of a French experimenter, Huguenard, in 1924. Huguenard was one of a group of French scientists who borrowed the compressed air plant of the Compagnie Parisienne de l'Air Comprimè, ordinarily used to supply air for a pneumatic system for transferring mail from one post office to another in the city of Paris. The air was borrowed to drive a 3-inch supersonic wind tunnel for testing models of artillery projectiles at supersonic speeds. Huguenard made the following observations: "Alone among all the methods of transportation, aviation has shown, from its very beginning, an extraordinarily rapid increase in speed. From about 33 miles per hour in the first flights, we have progressed in 21 years to more than 270 miles per hour, the speed doubling regularly every five or six years. This is certainly not accidental. At each new performance, pessimistic calculators, accepting with more or less grace the results already obtained and arming themselves with formulas borrowed from other modes of locomotion, have somewhat advanced the limit they had previously set to the speed of aircraft, whereupon this new limit has been promptly exceeded. Since there is no indication of any change in the speed curve (aside from technical considerations, which have thus far amounted to nothing) we must logically expect aircraft to attain speeds of the order of 540 miles per hour within five or six years. (1929 or 1930). The high velocity wind tunnel will doubtless be an important factor in solving the problem as to what new means of propulsion will be required."

Huguenard's only error was the use of a geometrical rather than an arithmetical progression. Until the advent of the jet engine the aircraft speed record increased more or less regularly at the rate of about 14 miles per hour per year and it required another 20 years rather than the predicted 5 or 6 to reach the predicted speed. Speeds of tactical military aircraft lag the speed record by a few years and the speeds of commercial aircraft lag by about 15 years.

Aeronautical progress requires men of expanding vision but not visionaries. The first goal was of course merely to fly. Immediately that goal was attained, the vision was expanded to airplanes which would fly faster and further, as illustrated by the predictions just quoted. For a long time the speed of sound (765 miles per hour at sea level, about 660 miles per hour in the colder air at high altitude) appeared to many to be an upper limit established by Nature, this in spite of the fact that artillery shells have long been fired at speeds far exceeding the speed of sound. Today this barrier has practically disappeared with the coming of jet and rocket power plants and of better knowledge of supersonic aerodynamics. The goals again move upward and the conservative prophets set new physical limits set by the aerodynamic heating of bodies which move too rapidly through the air. Excessive heating reduces the strength of the aluminum alloys commonly used. By going to higher altitudes where the air is less dense and to other materials the permissible speed can be increased. New problems appear, which, however, seem capable of solution.

The development of the V-2 rocket has greatly stimulated thoughts of much more radical developments, beginning with possible transport of passengers and freight for long distances over the earth's surface at speeds of several thousand miles per hour and the concomitant application to intercontinental warfare. From this it is but a step to consider vehicles which will leave the surface of the earth to become man-made satellites of the earth and a slight additional outreach of the mind to interplanetary travel, or, if that seems too great a step, at least to travel in space as far as to the moon.

At some point in this progression the visions are not realizable visions but mere dreams. Many competent people feel that a satellite vehicle is perfectly feasible from a purely technical point of view, and I am inclined to agree that the technical problems are soluble with a large but finite amount of manpower and money. I must add that at present I believe that there are more important fruitful ways of spending the money and manpower.

To give you some of the flavor of the thinking of the dreamers, I wish to quote a little from an article by H. E. Ross entitled "Orbital Bases", which appeared in the January 1949 issue of the Journal of the British Interplanetary Society. Many of the members of this Society are competent engineers and scientists. This paper discusses travel to the moon, pointing to the reduction in overall energy requirements which occur if, instead of postulating a journey direct to the surface of the moon and return, we consider splitting up the voyage into easy stages and refueling our space ship in space. This is to be accomplished by the establishment of manned satellites or space stations, assembled and constructed in space from the cargos of several space ships. The author estimates that for every three 442-ton rocket-propelled space ships it might be possible to get 30 or 40 tons of materials to an orbit of 24-hour period about the earth. He observes that "ability to rendezvous in space is an essential concomitant of this type of project but that although the difficulties are indeed formidable, they do not appear insuperable."

The space station is described as follows: "The station consists of three principal parts: (1) the 'bowl'; (2) the 'bun'; (3) the 'arm'. The bowl is a 200 foot diameter mirror; in this version a parabolic annulus, but other forms are possible. This mirror is used to collect and concentrate the sun's rays on to a system of pipes situated at the focus of the mirror. These pipes contain a fluid (let us say water or mercury) and they connect with 8 turbo-generators situated around the circumference of the 'bun' behind the 'bowl'. Boiling of the liquid by the trapped solar energy operates the turbines which in turn generate electricity for the station's various services. About 3900 kilowatts of solar energy is intercepted by this aperature mirror, so that we might reasonably expect that some 1000 kilowatts would actually become available for use.

"The 'bun' behind the mirror constitutes the living quarters, laboratories, workshops, etc. Since it is highly probable that entire absence of gravitational datum is undesirable physiologically, and certainly would be a considerable nuisance when moving about, it is necessary to rotate the inhabited part of the station. . . . . With the bowl and bun rotating once in 7 seconds, the g three feet from the floor of the two galleries will be 1.0 g in the outer and 0.43 g in the inner, which is probably a satisfactory compromise."

There follow proposed solutions for other technical problems, estimates of food, air, and water requirements, etc. To continue quoting: "I must leave to your own imaginations the peculiarities of living aboard one of these artificial satellites, with its upcurved floors that give the impression that one's colleagues are about to fall down, and its concave billiards table that looks impossible but on which the balls roll quite normally. . . . . Once it becomes possible to build space ships capable of achieving orbital velocity, a number of other schemes fall into line for consideration. For example, an enormous saving in electrical power would be effected if we could rely upon having a full moon every night--or better still, the equivalent of several full moons simultaneously. Who knows?--perhaps at some time in the future we may indeed have several swarms of objects like silvered table-tennis balls moving in an orbit around the earth and providing additional illumination at night; though, of course, such a swarm would have to be very big indeed, certainly not less than 10 miles across, and perhaps even 240 miles or more in diameter, depending on distance to equal the brilliance of the full moon."

I have quoted from this article at some length to illustrate a type of mental activity that is decidedly above the level of popular imaginative fiction but which correspondingly does not represent a safe foundation for an engineering undertaking. Like the concepts of flight during the 19th century, these concepts are the result of attempts of imaginative men to see how the technology of their day could be applied to solve the problems of interplanetary travel. I am reasonably sure that the accomplishment of travel to the moon will not occur in my lifetime and probably not in yours. The missing requirement is a still broader basis of experience in science and technology. Experiment and more experiment, unanticipated scientific developments in apparently unrelated fields, and probably the loss of many human lives in hazardous pioneer flights, are prerequisites to successful accomplishment of this goal.

The technical aspects of accomplishment in aeronautics are not the complete story since there are also the more important human and social aspects. Our material accomplishments are but tools for the purpose of accomplishing human ends whether those ends are for the benefit or to the harm of the human race. In this area also there must be men of vision to perceive what can be accomplished, to set the goals, and to bring about accomplishment of the goals. The vision of men who build and operate air routes to accelerate trade and intellectual and spiritual contacts between nations and to overcome natural barriers is as necessary as the vision of the men who design and build aircraft.

In any of these areas, the vision must be an expanding one toward larger goals. Neither the individual nor the race can stand still. Both must go forward rising on the shoulders of the past and impelled forward by what the human mind can conceive.

Expanding Accomplishment

Expanding vision leads to expanding accomplishment. I have already discussed briefly how accomplishment has expanded from the solo effort of the inventor to the symphony of the team. It seems to me that we are turning a corner in the pathway to an era in which even this concept is inadequate. After all, the score of the symphony can be broken down into separate scores for each instrument. A coordination is necessary as regards time, melody, and harmony but this can readily be accomplished because of the details of the score for each instrument can be worked out, once the general structure of the composition is given, with little interference or interaction.

Prior to World War II the design problems of an airplane could be readily broken down into aerodynamic problems, power plant problems, structural problems, electrical problems, hydraulic problems, etc., and each group could work out the optimum solution from its own specialized point of view with comparatively little interference. The most necessary coordination was a purely dimensional one, to see that space was available as required, that mating parts would fit and operate without mechanical interference. There were of course a few problems of a different nature such as the effect of the propeller slipstream on the stability and control which required consideration and optimization of the mutual effects by the propeller and stability groups. Similarly the drag associated with cooling required joint study by the power plant and aerodynamics groups. As speeds increased, the aerodynamicist began to complain of the many crude excrescences demanded by the electronics group for radio and radar antennae. As structural design was refined, the mutual effects of aerodynamic loads on structural deflection and of structural deflection on aerodynamic loads introduced borderline problems of flutter and aeroelasticity. Modern power plants swallow so much air that the separation of thrust from drag becomes almost only a matter of definition. The interaction between power plant and flow around the airframe is so great that experiments on the whole configuration with operation of the power plant present or simulated become almost indispensable. High speeds show up the limitations of the human body as a servomechanism for responding to stimuli, and a whole new science of automatic control of aircraft is being born.

In all of these cases the mutual interactions are large and a functional coordination is required. New methods for systems analysis must be devised. Complexities of a new type are introduced. The problem differs from one which involves merely the pyramiding of a large number of similar elements as one does in building a large apartment house as compared with building a single house. The only difference is in the number of bricks and workmen required. In the past the building of a large aircraft differed from that of building a small one in that many more people were required to do the detail design of many more joints and pieces. The building of a modern high speed aircraft or missile today requires a new concept of team activity and functional coordination, and a team consisting of more kinds of specialists with knowledge of more scientific fields. The apparent slowness of guided missile development stems from these new requirements. The teams had to be assembled and learn to work together. They had to learn the nature of the intricate problems and methods for their solution by actual experience. They had to develop methods of system analysis and to overcome unforeseen problems.

The implications for engineering education are clear. The new generation of leaders in aeronautical engineering requires a broader base of scientific knowledge, less intensive, narrow specialization, and the development of skills for making compromise decisions involving problems in several scientific disciplines. Techniques for still greater cross-fertilization of ideas between different specialties will be beneficial. Along with all of this we must have some specialists as well. The pyramid constituting the team is broadened by adding persons with new skills hitherto unknown, retaining all of the previous members of the team from unskilled laborer to expert scientist.

The development of these new skills and new methods of functional coordination expand the scope of possible accomplishment. As vision expands, as the stockpile of results of basic and applied scientific research accumulate, as better materials and better methods of manipulating them become available, as more suitably trained and competent design teams begin to operate, both the actual and the possible accomplishments expand, and visions, hitherto unrealizable, become practical engineering projects.

In conclusion, I return to my original theme. Any worthwhile accomplishment, though finally implemented and realized by a large and highly competent group of men, was first a vision in the mind of some one man. To the degree that each member of the group is a man of vision, to that degree can the accomplishments of the group far surpass the possible accomplishments of any single individual. The limits of accomplishment are set only by the size, experience, competence, and vision of the group. I commend to you the development and exercise of your powers of vision.

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